TITAN BALLOON BUOYANCY CONTROL ANALYSIS AND DEMONSTRATION

Final Report

JPL Task 969

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A. OBJECTIVES

Titan, the largest moon of Saturn, is the only moon in our solar system with a significant atmosphere, and it happens to be ideally suited for balloon exploration. The nitrogen atmosphere has a pressure a bit higher than Earth's, and it is much colder at -180ºC (Reference 1). This makes the density of the atmosphere four times greater than at Earth, and thus helium balloons can carry four times more payload. Titan is believed to have large, solid, land masses and cold, liquid-hydrocarbon oceans. The goal of this program is to design, fabricate, and test a buoyancy-controlled balloon system for Titan that will allow complete atmospheric mobility below the methane-ice-cloud level (10 km altitude), and that can travel about the solid surfaces and liquid seas.

B. PROGRESS AND RESULTS

A number of balloon buoyancy and mobility systems have been considered, and the design with the most flexibility to accomplish all mobility-related science objectives has been determined to be a blimp modified with a large floatation wheel (Figure 1), that can land and operate on cryogenic solid surfaces or liquid seas (Reference 2).

One possible mission scenario is shown in Figure 2. After entry into Titan's atmosphere, a parachute would pull out a deflated blimp. While falling, the blimp would be filled with helium, or hydrogen, and would gently descend to the surface due to a slightly positive weight. The Aerover could then reascend, using propeller power or by heating the blimp cavity with waste heat from a radioisotope thermal generator (RTG). The blimp could make repeated descents to the surface through direct commands from Earth or by autonomously seeking certain targets, such as biosignatures or heat sources. Although the surface winds are anticipated to be only about 0.5 m/sec (1.1 mph), at 10-km altitude the winds are strong enough to allow complete circumnavigation of the moon every one-to-two weeks. The Aerover would essentially be "orbiting" Titan well below the upper, obscuring clouds and could, for the first time, allow detailed imaging of the moon, which appears only as an orange disk from space.

Initial testing of Aerover concepts was begun with scale-model Aerover mobility tests. The first Aerover model tested was a commercially available one-meter blimp that was modified to allow surface mobility (floatation/landing wheel added), with heat-activated altitude control (black patch added to absorb external radiant heat). The model exhibited excellent control both in the air and on solid surfaces. Altitude variations were fully controllable by engine fan thrusts, by radiant heat input (ascent), and convective cooling (descent).

A larger, six-meter commercially available blimp has since been purchased and has been modified for testing as a Titan Aerover (Figure 3). A landing floatation wheel has been added that has allowed the blimp to land on solid land or lakes. The engines are rotatable to allow powered ascent. A series of internal, lightweight, heating coils has been added, representing waste heat additions inside the blimp, and a thermal model of the system has been created. The measured buoyancy change has closely matched those analytically predicted (Figure 4). The thermal model has further been exercised to demonstrate the effect of wind on blimp heating, and the results show that the blimp cools significantly, even for very low wind speeds (Figure 5). A number of power vs. velocity measurements have already been made, as well as power vs. thrust measurements. These values have been compared with various numerical models for forward motion, as well as for up-down motion. Results are discussed in the next section.

C. SIGNIFICANCE OF RESULTS

There are several primary areas of significance for the results thus far. The first is that a combined aerobot/rover, or Aerover, appears to be the best means to explore the atmosphere, solid surfaces, and liquid oceans of Saturn's moon Titan. The second is that power measurements made on a 6-m blimp have confirmed a novel, empirical correlation (Reference 3) made by this task's science advisor, Professor Ralph Lorenz. Based on these calculations, approximately 90 watts of power (out of 110 watts available) are required to propel our 12.5-meter long, 200-kg Titan Aerover at a speed of 1.0 m/sec, which is adequately above the 0.5-m/sec anticipated surface-wind speeds at Titan. We have also calculated that this speed can be increased for the same power if the propellers are more efficiently designed. In fact, our mobility models now predict that optimized propeller design will allow 2-m/sec velocity with only 50 watts of power.

The third significant result is that our thermal models are accurately predicting buoyancy change as a function of waste heat input to the blimp (Figure 4). Due to Titan's low gravity, low temperature, and dense atmosphere, the lift created by adding 200 watts of heat inside the 12.5-m blimp is about 3.7 kg while the blimp is floating with the wind, but with a relative wind of 2 m/sec, the buoyancy increase is reduced to only 0.73 kg (Figure 5).

Several other buoyancy factors have also been analyzed with blimp mobility models. At slow speeds, ailerons will create less than 1 kg of buoyancy, while low pressurization of the blimp ballonet chambers with ambient nitrogen (1000 Pa or 0.15 psi) will change buoyancy by about 2 kg. Vectoring the propellers upward or downward, however, can change buoyancy by as much as 39 kg, based on Titan's low gravity, and this can cause 1 m/sec vertical velocity. Vectored propellers are thus now considered the preferred primary means to control buoyancy of blimp aerobots on Titan.

D. FINANCIAL STATUS

The total funding for this task was $100,000, all of which has been expended.

E. PERSONNEL

Other personnel contracted for this study include Tim Lachenmeier, President of Global Solutions for Science and Learning, as well as Professor James DeLaurier of the University of Toronto's Institute for Aerospace Studies.

F. PUBLICATIONS

[1] Jack A. Jones, "Titan Amphibious Aerover", AIAA Space 2000 Conference, Long Beach, CA. September 19-21, 2000.

[2] Jack A. Jones, "Inflatable Robotics for Planetary Applications", 6th International Symposium on Artificial Intelligence, Robotics, and Automation in Space", i-SAIRAS, Montreal, Canada, June 19-21, 2001.

[3] Jack A. Jones and Ralph Lorenz, "Titan Aerover All-Terrain Vehicle", Space Technology and Applications International Forum (STAIF-2002), Albuquerque, NM, February, 2002.

[4] Jeffery L. Hall et al, "Titan Airship Explorer", IEEE Aerospace 2002 Conference, Big Sky Montana, March 2002.

[5] Ralph D. Lorenz, "Flight Power Scaling of Airplanes, Airships, and Helicopters Applications to Planetary Exploration", Journal of Aircraft, Vol. 38, No. 2, March-April 2001.

[6] Jack A. Jones, "Aerover Development at JPL/NASA", SPIE Unmanned Ground Vehicle Technology Video Session", Orlando, Fl, 2002, JPL Video #2002_01_02.

[7] JPL Titan Aerover URL (updated July 2001): http://www.jpl.nasa.gov/adv_tech/balloons/outer.htm

G. REFERENCES

[1] Ralph Lorenz 2000 Post-Cassini Exploration of Titan: Science Rationale and Mission Concepts, Journal of the British Interplanetary Society, Vol. 53, pp. 218-234, 2000.

[2] Jack A. Jones and Ralph D. Lorenz, “Titan Aerover All-Terrain Vehicle”, Space Technology and Applications International Forum (STAIF-2002), Albuquerque, NM, February, 2002.

[3] Ralph D. Lorenz, “Flight Power Scaling of Airplanes, Airships, and Helicopters: Application to Planetary Exploration”, Journal of Aircraft, Vol. 38, No. 2, March-April 2001.

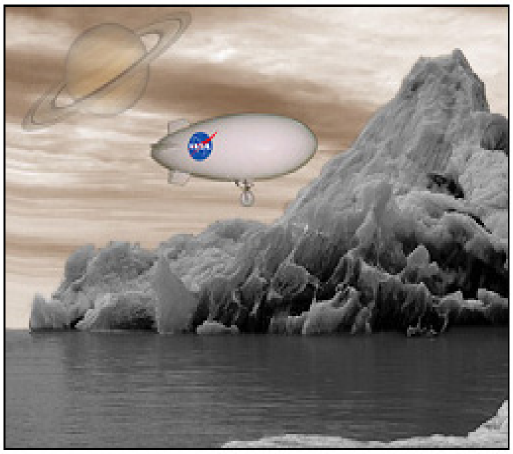

Figure 1. Titan Aerover

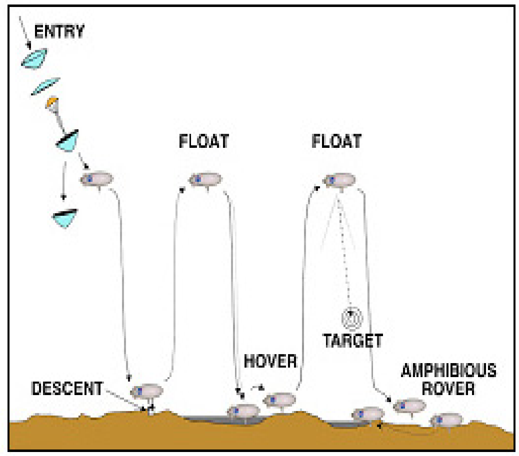

Figure 2. Mission Sequence

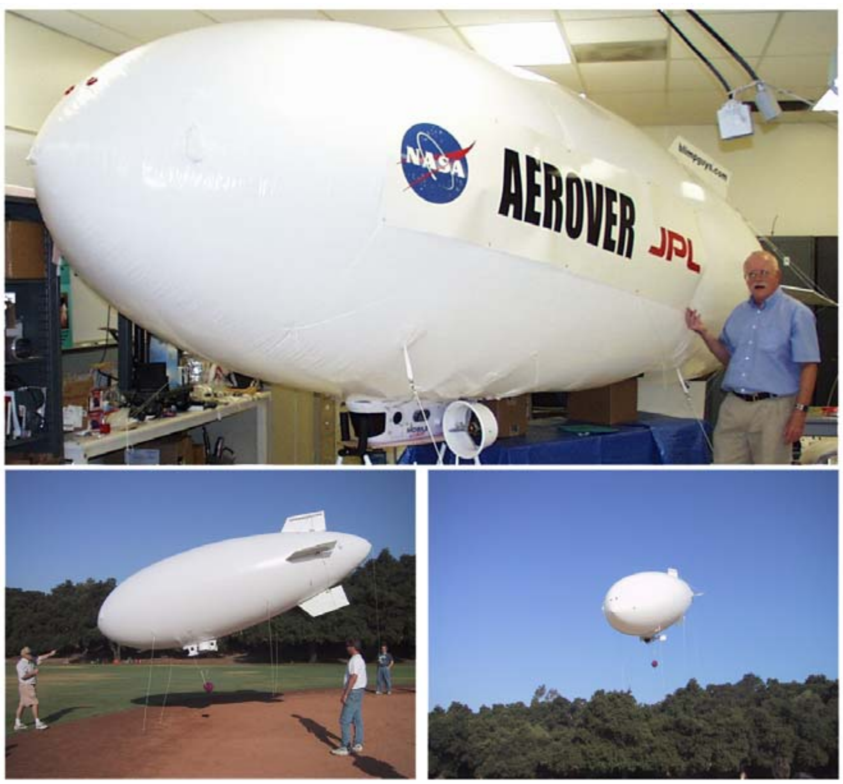

Figure 3. Titan Aerover Tests

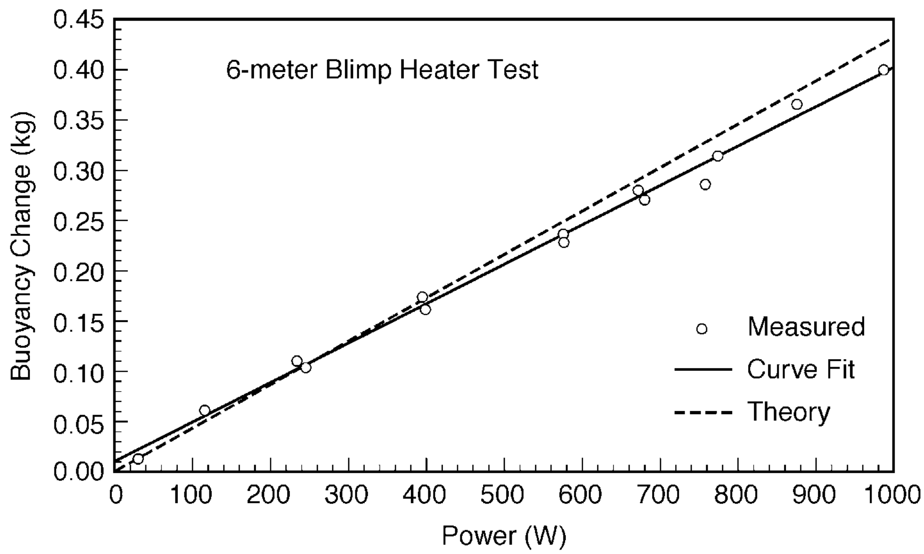

Figure 4. Buoyancy Change vs Blimp Heat

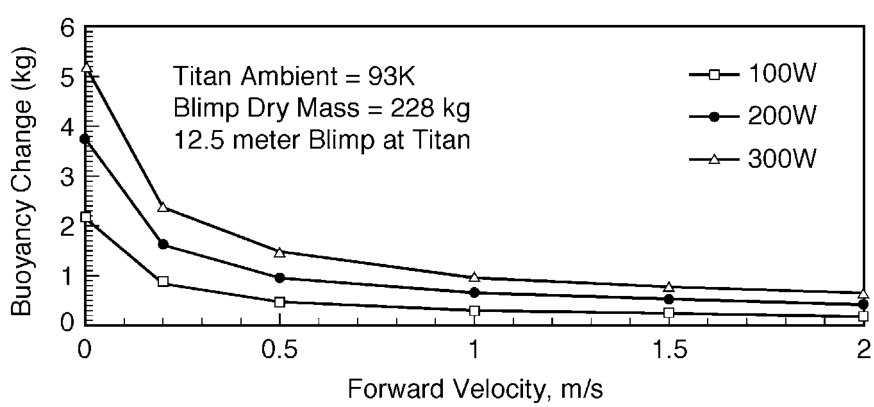

Figure 5. Buoyancy Change vs. Forward Velocity for Varying Heat Loads